CURRENT TASKS

White Sands Test Facility

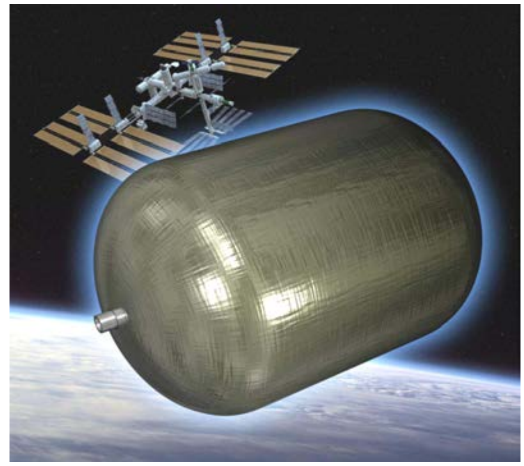

Fig. 1. NORS COPV used to transport oxygen and nitrogen to the International Space Station.

Task

Development of Critical Profilometers to Meet Current and Future NASA Composite Overwrapped Pressure Vessel (COPV) Inspection Needs

Center Points of Contact

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Objectives

This project is part of a multi-center effort to develop and validate critical NDE techniques which can be implemented into current and future NASA spacecraft COPV manufacturing processes. After decades of COPV development, manufacturing variance is still high and has necessitated higher safety factors and additional mass to be flown on spacecraft (reducing overall performance). Additionally, the NASA Engineering and Safety Center (NESC) indicated that nondestructive evaluation (NDE) was not adequately implemented during Shuttle and International Space Station (ISS) COPV manufacturing and provisions were not made for on-going structural integrity and health checks during the various spacecraft programs. This project helps to provide additional data needed to help address these issues.

Fig. 2. Original ‘desktop’ internal COPV profilometer developed.

This project seeks to develop and install internal and external laser profilometers at COPV manufacturing facilities to provide data needed to improve COPV quality and consistency. As an extension to research conducted at WSTF, the project targets COPV applications such as NNWG stress rupture test vessels, ISS stress rupture test vessels, Oxygen Recharge System (NORS, Fig. 1) and Orion COPVs. New innovations such as articulated probe designs are also to be developed to allow both the cylindical portion and ellipsoidal heads to be accurately mapped and measured. By using these profilometers, manufacturers can evaluate mechanical response to manufacturing processes and eliminate vessels that have “out of family” characteristcs, resulting in less variability in the final product. The vessels that would be screened out include those that have areas of lower modulus and greater deformation autofrettage. The profilometers developed also combine measurement and imaging capabity eliminating the need to borescope vessel interiors. Implementation of this system into manufacturing facilities is also expected to further evolve the design of COPVs by providing an understanding of how outer

composite plies affect lower plies and how they respond to autofrettage or plastic liner deformation.

This project also investigates other scanning techniques that will enhance the system to more completely meet manufacturing needs, thus transforming the profilometer into what has been termed the “Universal Manufacturing COPV Scanner”. This enhancement involves the application of easily interchangeable probes/sensors with selectable software for either eddy current (EC) liner crack detection or captured water column focused ultrasound (CWCFU) void detection capabilities to the COPV scanner.

Fig. 3. External profilometry added to desktop scanner.

Accomplishments

Accomplishments to date include the following:

1) Developed the original COPV laboratory desktop-type internal profilometry scanner (Fig. 2) in 2009.
2) Modified the original scanner to add external profilometry (Fig. 3) and EC mapping capability (Fig. 4) in 2010.
3) Developed a high accuracy X-Y scanner (Fig. 5) for impact evaluation in 2010.
4) Developed an articulated sensor (Fig. 6) to scan the interior of large cylindrical COPVs with ellipsoid ends in 2010.
5) Accomplished extensive testing and data collection in 2009-2011:
   a) Mapped and measured ISS stress rupture test vessels during manufacturing at General Dynamics providing detailed mechanical response mapping from bare liner to wrapping and autofrettage.
   b) Mapped NESC COPV thickness variations using digital subtraction from internal and external scans.
   c) Mapped and measured the stress rupture response of NNWG COPVs.
   d) Characterized impact damage to COPV coupons using the X-Y scanner in 2011 (Fig. 5).
   e) Verified the performance of the articulated Orion profilometry system in 2011 by mapping the COPV including ellipsoid domes (Fig. 6).
6) A new ISS NORS articulated probe was developed, validated, and delivered in 2011 (Fig. 8).
7) The NORS profilometer mapped a prototype (Dev. 4) vessel liner, wrapped liner and autofrettaged COPV in 2012.
8) Developed four new EC sensors in coordination with UniWest and initiated characterization of performance on outside and inside of the liner and through the composite in 2012.
9) The team is currently implementing the NORS profilometer in a COPV production facility in 2012.

Fig. 4. External eddy current probe added to desktop scanner.

Fig. 5. X-Y Scanner developed.

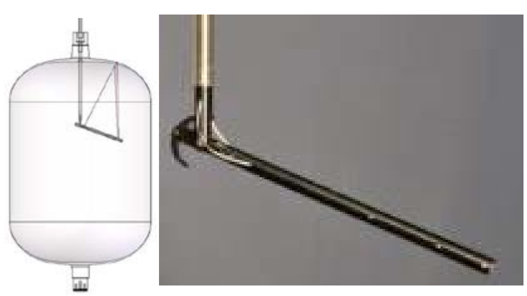

Fig. 6. Articulated sensor developed

Customers

The direct customers for this task will be the ISS, Orion, In-Space Propulsion/Planetary programs, and others related to NASA's Space Exploration Initiatives. Indirect customers are all other space flight system that employ COPV technology. The results developed could be used across the agency, DOD/DOT, and in commercial aerospace and hydrogen powered vehicle applications.

Fig.7. 12 foot tall Orion system shown with simulator vessel

Metrics

Progress shall be reported on an annual basis and peer reviewed by NNWG members. A comparison shall be made to the original project plan and schedule, providing a measure of project progress. Additionally, the NESC Composite Pressure Vessel Working Group is a stakeholder, and this proposal has their expressed endorsement.

Conclusions and Future Work

Overall, the project has been an overwhelming success. The systems are aiding manufacturers in developing more consistent COPVs which are benefiting NASA programs and manufacturers as follows:

1) Manufactures can evaluate mechanical response and eliminate vessels that have "out of family" response, resulting in less variability in the final product.
2) The systems combine mapping, measurement and imaging eliminating the need to borescope vessel interiors (Fig. 10). Therefore, NDE methods are combined to save time.
3) The ISS NORS system was successful completed and is being implemented in the NORS manufacturing facility (Fig. 8).
4) Although the Orion profilometer was developed, the rescoped program eliminated the original urgent need, and minor improvements are now highly desirable prior to utilization in approximately one year.

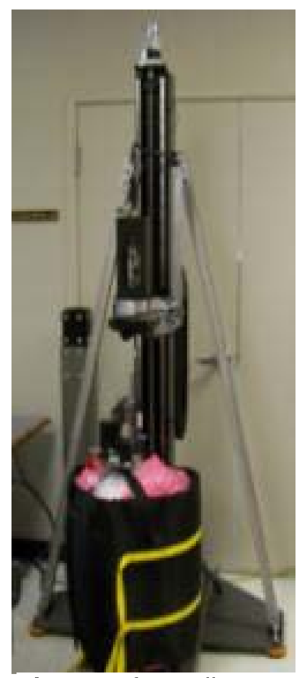

Fig. 8. 7 foot tall NORS system developed and being used by the ISS NORS Program

Interactions with COPV manufactures and key representatives from the COPV technical community clearly indicate the importance of adding the previously identified NDE capabilities into a "Universal Manufacturing COPV Scanner", shifting future efforts toward augmenting the desktop scanner to detect liner cracks (EC, external and internal) and composite flaws (CWCFU).

Example: COPV in Process Analysis

Liner features can be mapped, measured, and tracked between manufacturing phases as shown below in an example vessel (Fig. 9). In the example shown surface irregularities decreased in both magnitude and spread during each manufacturing phase. A thin 2-in. square Teflon® PTFE insert was also installed on the liner during the wrapping process to simulate delamination. The simulated delamination was easily detected in the internal profilometry scan, but was noticeably absent from the autofrettaged scan. Welds and surface roughness features were mapped and are clearly visible in a laser intensity scan (Fig. 10).

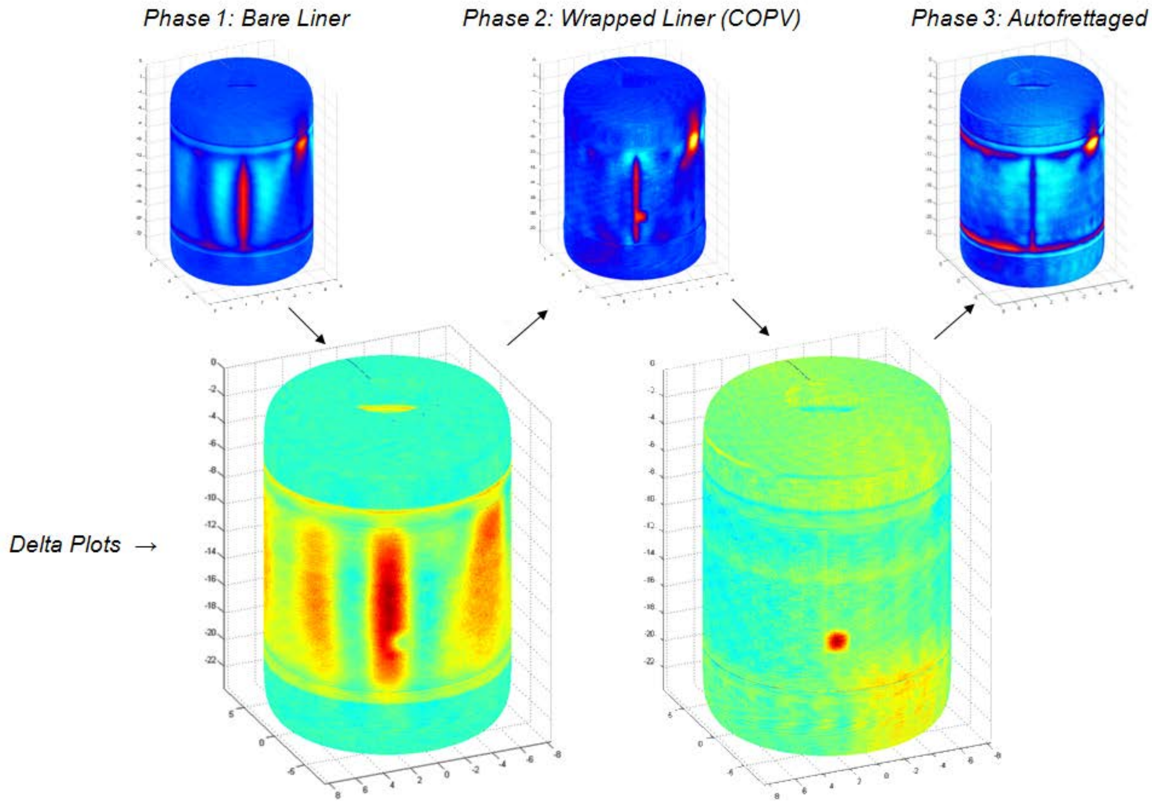

Fig. 9. Profile scans for a developmental vessel through all manufacturing phases. (Note the decrease in rippling observed during the construction phases and the prominent indication associated with the Teflon insert simulating delamination (bottom, right)).

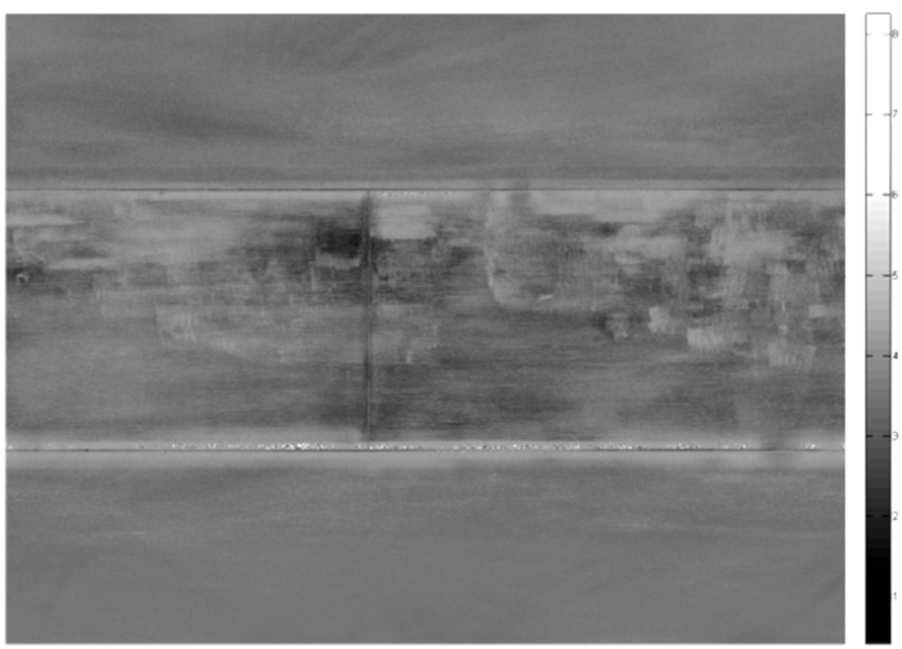

Fig. 10. Interior laser view of a vessel with ellipsoid end caps.